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Noah's Ark: Longitudinal Strength Based on Trusses

John Woodmorappe

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NOAH'S ARK: LONGITUDINAL STRENGTH BASED ON TRUSSES

John Woodmorappe, MA Geology, BA Biology

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ABSTRACT

This engineering work computes the wave-induced bending stresses upon the Ark, and then evaluates a series of internal trusses to carry the entire bending load. The joints, notably the metal dowels resisting lateral loads, govern the design. For a small-cubit Ark with trusses at a 45 degree web/chord angle, and 0.8 wood density (g/cm^3), the required trusses consumed 12% of the volume of the Ark and 20% of its displacement, and required 25,000 board feet of structural wood. The large-cubit Ark is more efficient than the small-cubit one in terms of percentages taken by interior trusses, but requires much larger timbers for the construction of these trusses.

INTRODUCTION

The Ark, when modeled as a giant box beam in which the low-shear-modulus hull resists the bending load by itself (Woodmorappe 2008), is limited by shear lag. To circumvent this, the Ark is designed so that multiple coplanar trusses serve as auxiliary internal "webs" in the interior. (Fig. 1).

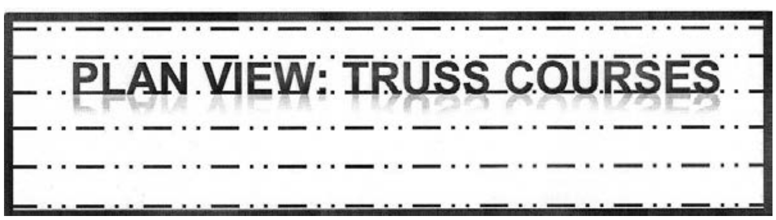

Figure 1. Six courses of trusses span the length of the Ark.

UNEVEN BUOYANCY IMPOSES BENDING LOADS

A long-hulled structure encounters wave-induced bending moments that maximize whenever the wavelength of the trochoidal wave is comparable to that of the hull. Peak sagging occurs when the ends of the hull are lifted up by the crests of adjacent waves, causing the middle of the hull to droop in the wave trough (Fig. 2). Seconds later, peak hogging occurs when the middle of the hull is uplifted by the crest of a large wave, causing the ends of the hull to droop as overhanging beams. Owing to the low frequency of such waves (~0.1 Hz.), caused by the fact that each one takes over 10 seconds to pass under the Ark, the loading on it can be treated as essentially static.

In the ocean, large trochoidal waves are generated by wind-generated storms. They affect a small fraction of the ocean at any one time. It is unclear how common large storms were during the Flood itself. Assuming sufficient depth of Floodwater, waves produced by seismic events had wavelengths very much greater than the length of the Ark, with negligibly small crest heights. However, shoalings, along with destructive interference of waves, undoubtedly could have created Ark-length waves.

WAVE-INDUCED BENDING LOADS ON THE ARK

Standard shipbuilding formulas (MacDuff (p. 237) in Murray (1966), based on the inferred severest situation in a lifetime of a ship at sea, were used to estimate the design bending forces on an Ark-sized hull. Assuming that the design formulas are reckoned on something like 100 ships each operating 50 years at sea without a single bending-load hull failure, this implies that the severest bending load upon the Ark during the one-year Flood corresponds to the severest bending load during 5,000 ship-years today at sea.

Sagging (Fig. 2) imposes greater bending stresses than hogging. (MacDuff (p. 237) in Murray 1966). Hogging, instead of examined separately, was tacitly treated as a mirror image of sagging, with the Ark cut in the middle, perpendicular to its length, and its ends rotated until they touch.

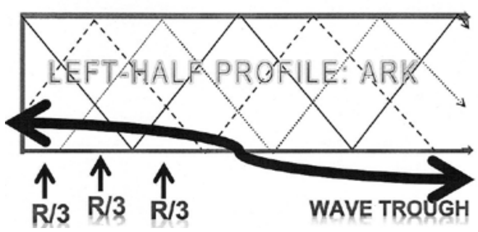

Figure 2. Three trusses per truss course. Reduced buoyancy in wave troughs.

From the design bending moment, an effective weight of the Ark, in water and subject to maximal sagging and hogging forces, was computed. The effects of buoyancy remained dominant. The effective weight of the Ark, while hogging and sagging, was still less than 10% of the Ark simply supported at its ends in air.

DESIGN OF TRUSS WEBS

Speculations about the advanced nature of the antediluvian civilization are eschewed in favor of the conservative assumption of simple, unremarkable technologies. For instance, use of drift pins (large nails) in ship construction is known, from nautical archeology, to be ancient. (Fitzgerald 1995).

The following is a summary of the largely interactive calculations that were used in an unpublished spreadsheet. A design hull-bending load was computed. The trusses and their joints were designed. Later, some of the variables interactively examined were Ark cubit size (44.7 cm vs. 66.55 cm), density of wood (0.5, 0.8, 1.1) as a proxy for mechanical properties, and web-chord angle (45 or 60 degrees). (Table 1).

Cubit	ρ	Θ	t	w	%Vol	%Disp
66.55	0.8	45	144	483	6	10
66.55	1.1	45	144	406	6	14
66.55	0.8	60	209	635	7	11
66.55	1.1	60	209	432	7	16
44.70	0.8	60	123	254	9	14
44.70	1.1	60	123	178	9	19
44.70	0.8	45	144	178	12	20
44.70	1.1	45	144	178	12	27
44.70	0.5	45	144	813	15	15
66.55	0.5	45	144	813	15	15
44.70	0.5	60	209	1,600	17	17
66.55	0.5	60	209	1,600	17	17

Table 1. Most to least efficient Arks in terms of the variables examined.

Owing to the complexity of the interaction between trusses and hull “skin”, the latter was ignored structurally, and the trusses were conservatively assumed to resist the entire bending load. Note that this approach facilitates designs of the Ark with relatively large doors and windows. Such structural liabilities significantly reduce the bending resistance of the already low-shear-modulus hull “skin”, thus making its unimportance, in terms of resistance to such loads, a desirable feature.

The trusses were deployed in six courses, one of each near an Ark side. (Fig. 1). This created long alleyways, each 10 cubits wide, running the length of the Ark. This enabled livestock enclosures, stored foods and water, and passageways to be deployed in a manner consistent with the efficient use of human labor. (Woodmorappe 1996).

Although composite trusses (Fig. 2) are statically indeterminate, they can be broken down into a series of statically-determine ones on the assumption of equal load-sharing. (Hool and Kinne 1942, p. 284). Thus, the maximum reaction force borne by any truss element was computed, and this was taken as the design load for each web member. To cover deviations from the assumed equal load-sharing, the design load was multiplied by a factor of 1.1. Warren trusses (according to relatively recent terminology) were the ones chosen because of their intuitive simplicity.

From this, the maximal axial tensile and compressive loads were calculated for each web element. To avoid problems with buckling, and needing to assume that Ark infrastructure and furnishings offered sufficient bracing, the cross-sectional areas of the webs were made large enough to avert buckling even with the absence of *any* bracing.

The design load, and required cross-sectional area to resist it, was calculated differently from that in bridge engineering, in which the outermost web member carries a diagonal component of 1R (the upward-acting reaction force). Since the sagging hull's ends are being supported by a spread-out wave crest, not a solitary point force, the overall reaction force (half the buoyed Ark weight) at each Ark end was first divided by the number of courses of trusses. The net reaction force (R) was subdivided by each of the three trusses per course, yielding R/3, and then by two webs of each bay, for a final burden of R/6 per web. The diagonal component of this constitutes the design force. The decreasing buoyancy effects of the trochoidal wave during sagging, going center-ward, was further reckoned by treating the Ark as a simply supported beam having progressively increasing weight towards the center.

WOOD DENSITY AS A PREDICTOR OF TIMBER MECHANICAL PROPERTIES

The wood used was assumed to be seasoned to the customary moisture content of 12% (Standards Australia 1998). The pitching of a wooden vessel, inside as well as out, done in order to prevent excessive absorption of moisture which can cause swelling and perhaps mechanical damage (Pardey 1991, p. 275), was applicable to the Ark. (Genesis 6:14).

Instead of using allowable loads culled from an engineers' table, an interactive approach was employed instead. Many mechanical properties of structural lumber correlate with wood density. To exploit this, a series of relevant characteristic strengths (weakest 5th percentiles) were graphed as a function of density. Equations were fitted to the regressions (r-squared commonly 0.95 or greater), and then these regressions were used to predict timber strength (in tension, compression, shear) of specified wood density. Wood is a highly anisotropic engineering material, and Hankinson's formula (AFPA 2005, pp. 161-163) was used to determine mechanical properties at angles intermediate between those parallel and perpendicular to the grain.

Some reduction factors, for characteristic values, have been used in design. However, owing to the fact that the web cross-sectional area is controlled by the joint (see below), and is greatly in excess of that needed to resist axial forces, potential disagreements about the applicability of reduction factors are largely moot.

DESIGN OF CHORD-WEB JOINTS

Wood does not conventionally lend itself to efficient force-transmitting joinery. The complexity of wood and its anisotropic nature further complicate the design of joints.

Conventional heel joints, which require a section of wood to be cut out of the chord (e.g., McCullough 1917, 1921), and which thus create major stress concentrations in the remaining section of chord, were avoided. Instead, an unmodified chord surface was used. The bearing requirements of the chord and web surfaces, at their mutual interface ("footprint" in Fig. 3), were determined, along with the effects of the force of friction in resisting part of the lateral component of the axial loads acting on the webs.

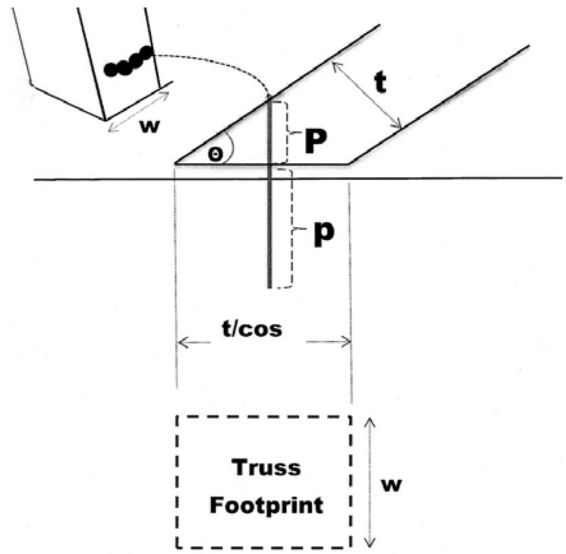

Figure 3. View in profile of web/floor/joint detail: Web-member thickness (t), width (w), and angle to Ark-floor chord (); dowel-penetration depth in web member (P) and floor (p).

One consequence of the choice of joint used (Fig. 3) is the fact that all of the lateral (except by force of friction) as well as the vertical-acting loads (cyclically in tension and compression) must be resisted by metal dowels. In this instance, they are drift bolts or drift pins—essentially giant nails driven into slightly undersize pre-bored holes.

To minimize the possibility of greatly unequal load sharing among dowels, none of them were deployed co-linear to the force acting upon them. Instead, they were all placed perpendicular to the force acting upon them. (Fig. 3, top left). To cover minor inequality of load sharing, a factor of 1.05 was introduced into the joint-related calculations. In addition, the avoidance of placing connectors in a row, with the realization that they would have to be in wood in changing cross-sections, further minimizes the potential problem of unequal load-sharing and/or complex secondary stresses.

The fasteners are assumed to have been made of Damascus-type steel, which goes back to antiquity. Amazingly, it has somewhat greater tensile strength and higher yield yield strength than modern mild steel. (Sherby and Wadsworth 1997, 2000).

The metal dowels, in turn, needed to be surrounded by a profligate amount of wood to be able to fully display their strength, and to be prevented from being separated from, or damaging, it. All this was verified by computations showing sufficient wood for spacing, bearing, resistance to pullout, and (on a separate spreadsheet program) Mode IV (bending of the dowel) as the mode of failure.

Dowels smaller than 5 cm (2 inches) in diameter proved to require an inordinate width of web width to accommodate their numbers with the required spacing between them. For this reason, 5 cm dowels were used in design even though mode-of-failure studies (e. g, Wilkinson 1993, p. 2174) only evaluated dowels up to 3.81 cm (1.5 inch) diameter. However, dowels of 5 cm (2 inch) and 7.62 cm (3 inch) diameter have regularly been used in timber engineering in the past. (Merriman 1916, p. 670, Langlands and Thomas 1948, p. 67, and Pun 1980).

Even with 5 cm (2 inch) dowels, considerable widths and thicknesses of timbers were needed for webs. This requirement needs to be kept in perspective. For instance, Honduras Mahogany (*Mahogani swietenia*), can yield planks over 2 meters wide (Judge 1921, p. 229), and the Australian blue gum (*Eucalyptus globulus*) has yielded planks 4.27 m wide and 36.6 m long (Wray 1859, p. 433).

SECONDARY STRESSES IN WEB-CHORD JOINTS

In most instances, eccentric loads in truss construction are neglected because they usually are unimportant. However, such loads are factored in the present study (Fig. 4), which also considers primary and secondary forces acting simultaneously.

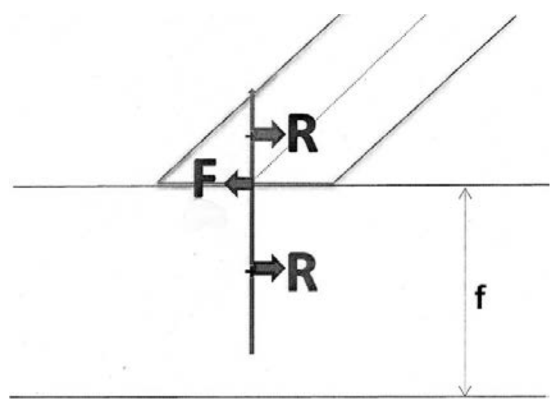

Figure 4. Eccentric web-chord joint: Force (F), reaction (R), and floor thickness (f).

Owing to the fact that the centroids of the forces and their reactions do not coincide, the web/chord joints are eccentric. The lateral component of the axial force (F)(tension or compression) is taken as concentrated along the centroid. The resistance (R) is concentrated at the center point of the top dowel (Fig. 4). This creates a moment that tends to break off the web end at the point of dowel insertion, and this is resisted by sufficient cross-section in the web member—in addition to its resistance against axial forces acting within the web member.

A second moment is created by the lateral force (F) resisted eccentrically by the reaction (R) at the midpoint of the dowel embedment in the chord (Ark floor or ceiling). This moment tends to break off a section of the chord that is under the web. It is resisted by a sufficient cross-section of chord—in addition to its resistance against axial forces acting within the chord.

RESULTS

Consider the interactive analysis (Table 1). The Ark requiring the least cross-sectional wood has a small cubit, timber density of 1.1, chord/web angle of 60, requiring a web thickness (t) of 1.23 m and web width (w) of 1.78 m.

Large-cubit Arks tend to be more efficient than small-cubit Arks, in terms of percentage of Ark interior volume and displacement consumed by the required trusses. The most efficient Ark is the large-cubit one, wood density 0.8, 45-degree web/chord angle, with truss-volume and displacement requirements of 6% and 10%, respectively. However, even the most-inefficient Ark still leaves plenty of room, and displacement, for the Ark cargo (Woodmorappe 1996).

The choice of web/chord angle in the trusses (45 or 60 degrees) is not crucial. It has less impact on large-cubit Arks than small-cubit ones.

Low density wood (0.5) exhibits poor mechanical properties and performance for an Ark of whatever size, and higher density wood (0.8) performs much better. However, any further improvement in substituting high-density wood (1.1) for medium-density wood (0.8) is largely nullified by the fact that the wood required for the spacing of dowels in the joint remains the most important factor in the design cross-section of the webs. More specifically, the number of dowels necessary to resist shear/bending controls the design.

Secondary forces in the joints are irrelevant for most chosen combinations of the variables. However, they become significant, even controlling, in Arks constructed out of wood of low density.

FACTORS IN THE ULTIMATE STRENGTH OF THE ARK

This work is conservative in a number of ways. As noted earlier, the resistance offered by the Ark walls has been omitted. The additional capacity of fasteners caused by end fixity (e. g., clenching of the connector ends) is not considered.

The forces allowed on timber and joinery usually have a built-in capacity for a onetime overload. In addition, there is a growing body of evidence that wood in general is significantly stronger in shear than expected from tests on small, clear pieces of wood. (Khokhar 2011). Some kinds of wood (e.g., from azobe) turn out to be significantly stronger than had earlier been supposed (from tests on small samples and extrapolations to lumber size). (Kuilen and Bass 2005).

Now consider redundancy in engineering. The more redundancy there is in the design of a structure, the better. This is especially true when biological materials, whose properties are much less predictable than manufactured materials such as steel, are used in the construction.

One level of redundancy is provided by the numerous truss elements within the Ark. Were one web element to fail even completely (rupture), its neighbors could take up the load. A secondary level of redundancy is provided by the dowels, which, as mentioned, are virtually independent of each other, and with generous spacing from each other. Thus, were one dowel, in spite of the Mode IV failure predicted, to nevertheless fail by significantly damaging the wood embedding it, this would be unlikely to damage the adjacent dowel-fastener assemblies, and still more unlikely to disable the entire web element to which it belongs.

Owing to the fact that the joint controls the design, the failure of an overloaded web member is very likely to occur there. This reduces the danger of harm to the Ark occupants, as opposed to the event of failure (breaking or buckling) of a web member. In addition, a Mode IV failure predicts a “ductile” failure (bending of the connector) over a “brittle” failure (splitting, crushing, and/or shearing of the wood), thus limiting the scale of the damage in the joint, and likely enabling the remaining connectors of the affected web to retain their function.

Finally, were all of the dowels in a web element to fail in bending, the web element could still offer some resistance to the axial forces. The very weight of the completely disconnected web element would offer some resistance to the axial tension force. The web/chord bearing, along with the force of friction acting at the web/chord “footprint” (Fig. 3), would offer some resistance to the axial compressive stress.

FUTURE RESEARCH

Once actual unequal load-sharing factors become known for web members, the overall calculations can be re-done with specific instead of assumed values. The same holds for unequal load-sharing within a joint.

A better understanding of the behavior of large dowels within large pieces of timber should be sought. Once found, the dowel spacings and embedments can be modified accordingly.

Finite-element analysis should be used to examine allowable deflection limits on the Ark during flexure, as well as the deflection caused by the trusses, truss, joints, and interactions of these with the chords. Lateral and torsional loads, along with slamming loads, should be considered along with the bending loads acting longitudinally on the Ark.

CONCLUSIONS

Trusses can demonstrably serve as a means of resisting wave-induced bending loads on the Ark, if timbers of adequate cross-section can be obtained. Moreover, they can work for small-cubit and large-cubit Arks, and at a considerable range of medium and high-density woods.

- The commonly-speculated identity of gopher wood (Genesis 6:14) is, from a structural standpoint, not crucial, as long as its density was well over 0.5.
- The Ark designers had a fairly wide latitude in the design of the Ark with trusses having web members at a range of acute angles to the floor and ceiling.
- The essential variables employed in the construction of suitable trusses within the Ark do not come close to challenging its capabilities in terms of interior space and displacement.
- The ability of Ark interior trusses to alone carry the bending loads allowed the construction of Arks with relatively large windows and doors.
- It appears that relatively simple technologies are sufficient for the construction of an Ark with adequate resistance to bending loads, and there is no need to invoke esoteric or advanced technologies for the construction of the Ark.

REFERENCES

AFPA (American Forest and Paper Association). 1999. *Commentary NDS For Wood Construction*. Washington, D. C., 204p.

AFPA (American Forest and Paper Association). 1999a. *General Dowel Equations for Calculating Lateral Connection Values*. Washington, D. C., 20p.

AFPA (American Forest and Paper Association). 2005. *National Design Specification for Wood Construction*. National Forest Products Association, Washington, D. C.

Australian Standard. 1997. *Timber Structures. Part 1: Design Methods*. Council on Standards Australia

Blake, A. 1990. *Practical Stress Analysis in Engineering*, 2nd Ed. Marcel Dekker, New York, 690p.

Dewell, H. D. 1918. *Timber Framing.* San Francisco, USA, 275p.

Fitzgerald, M. A. 1995. *A Roman Wreck at Caesarea Maritima, Israel*. PhD Thesis, Texas A and M University.

Gere, J. M. 2005. *Mechanics of Materials*, 6th Edition, Cenage Learning.

Hansen, H. J. 1948. *Modern Timber Design*, 2nd ed. John Wiley and Sons, New York.

Hool, G. A., and W. S. Kinne. 1942. *Stresses in Framed Structures*, 2nd edition. McGraw Hill Book Co., New York, London.

Judge, A. W. 1921. *Aircraft and Automobile Materials*, Vol., 2. London, Sir Isaac Pitman, 594p.

Khokkar, A. M. 2011. *The Evaluation of Shear Properties of Timber Beams Using Torsion Test Method*. Phd Thesis, Edinburgh Napier University, 151p.

Kuilen, J. W. G., and H. G. Blass. 2005. Mechanical properties of azobe. *European Journal of Wood and Wood Products* 63(1)1-10.

Langlands, I., and A. J. Thomas. 1948. *Handbook of Structural Timber Design*. Melbourne, Australia, 299p.

McCullough, E. 1917, 1921. *Practical Structural Design*. New York, 416p.

Merriman, M. 1916. *American Civil Engineers' Pocket Book*. John Wiley, New York, London, 1571p.

Murray, J. M. 1966. Development of basis of longitudinal strength standards for merchant ships. *TRINA (Transactions of the Royal Institution of Naval Architects)* 108:217-244).

Neubauer, L. W. 1973. A realistic and continuous wood column formula. *Forest Products Journal* 23(3)38-44.

NFPA (National Forest Products Association). 2005. *National Design Specification for Wood Construction*. Washington, D. C.

Pardey, L. 1991. *Details of Classic Boat Construction: The Hull*. WW Norton and Company, New York, London, 518p.

Pun, C. Y. 1980. Strength of bolted joints. *Malaysian Forester* 43(1)88-118.

Schierle, G. G. 2001-2008. *Buckling*. (online)

Sherby, O. D., and J. Wadsworth. 1997. *Ultrahigh Carbon Steels, Damascus Steels, and Superplasticity.* Lawrence-Livermore National Laboratory, California, USA.

Sherby, O. D., and J. Wadsworth. 2000. *Ancient Blacksmiths, the Iron Age, Damascus Steels, and Modern Metallurgy.* Lawrence-Livermore National Laboratory, California, USA.

Standards Australia. 1998. *Timber Design Handbook*. Council on Standards Australia.

Tucker. B. J. *et al*. 2000. Governing yield modes for common bolted and nailed wood connections. *Practice Periodical on Structural Design and Construction* 5(1)14-25.

USDA (United States Department of Agriculture). 1935. *Wood Handbook*. Washington, D. C.

USDA (United States Department of Agriculture). 2010. *Wood Handbook*. Washington, D. C.

Wilkinson, T. L. Bolted connection design values based on European Yield Model. *Journal of Structural Engineering* 119(7)2169-2186.

Woodmorappe, J. 1996. *Noah's Ark: A Feasibility Study*. Institute for Creation Research, El Cajon, California.

Woodmorappe, J. 2008. Noah's Ark Design: Factoring Partial Composite Action. *Proceedings of the 6th International Conference on Creationism*.

Wray, L. 1859. On timber for ship-building. *Journal of the Society of the Arts* 7:428-435.